Reference Architecture for Interoperability Testing of Electric Vehicle Charging

Felix Lehfuß, Martin Nöhrer
AIT Austrian Institute of Technology GmbH
Energy Department, Electric Energy Systems
1210 Vienna, Austria
{felix.lehfuss, martin.noehrer}@ait.ac.at

Ewoud Werkman
TNO
Service Enabling & Management
Delft, Netherlands
ewoud.werkman@tno.nl

José A. López, Eduardo Zabala
TECNALIA
Energy & Environment Division
Bilbao, Spain
{josea.lopez, eduardo.zabala}@tecnalia.com

Abstract—**This paper presents a reference architecture for interoperability testing of electric vehicles as well as their support equipment with the smart grid and the e-Mobility environment. Pan-European Electric Vehicle (EV)-charging is currently problematic as there are compliance and interoperability issues on different communication levels and among the different domains comprising the eMobility system. The discussed reference architecture is composed out of three layers that enable addressing a direct mapping of interfaces, functions and services, as well as real world actors and/or laboratory equipment. Utilizing this architecture enables cross-domain co-simulation for interoperability within the electric mobility and the smart grid environment. Given the future challenges that rise to interoperability testing and the fact that certain aspects are yet unknown or rarely defined, the discussed architecture presents a very modular and extendable approach.**

Keywords—reference architecture, compliance, interoperability, electric mobility, smart grid, testing, electrical vehicles

I. INTRODUCTION

With a steady increase of electric mobility, interoperability testing for such infrastructure becomes more and more apparent. Interoperability is not only required on a very basic level between the electric vehicle (EV) and the electric vehicle supply equipment (EVSE) (e.g., electrical interoperability) but also between the different eMobility actors and the smart grid environment. So the needs for compliance and interoperability on different communication levels and within different domains arise.

The first step towards compliance and interoperability was to identify or develop appropriate standards defining electric as well as communication interfaces. This not only holds for the vehicle interfaces but also for the management systems provided by eMobility service providers (e.g., reservation of a charge pole, smart grid and smart charging services, roaming). Today a set of appropriate standards is already available and the first step can basically be seen as finished [1,2]. The second step is however to develop and define test procedures that enable to ensure real interoperability between different actors, systems and components. In order to conduct such tests on a reliable basis they need to include cross-domain functionality validation: for instance a certain change on the energy path needs to result in a communication signal in order to trigger the required change of behavior. In order to be able to conduct interoperability tests that are comparable throughout multiple laboratories, a common test reference architecture needs to be defined.

This contribution discusses a reference architecture for interoperability testing of the electric vehicle charging infrastructure that was developed within the COTEVOS project.

COTEVOS [3] is a European project aiming at developing optimal structures and capacities to test the conformance, interoperability and performance of the different systems to be included in the infrastructure for the introduction of electric mobility into the smart grid. Based on a strong network of European research facilities COTEVOS is to set up the basis, tools and facilities to ensure the pan-European interoperability and conformance between the electric grid and the EVs, based on a relevant network of Smart Grid test beds.

A very well-known state-of-the-art model for the interfaces between the EV, the EVSE and eMobility service providers is the CEN/CENELEC/ETSI focus groups model [4]. This model describes a first approach and therein depicts the most important interfaces and interfaces that are prone to cause interoperability issues. Another reference architecture that is widely accepted in this domain is the Smart Grid Architectural Model (SGAM), created within Mandate 490 of the European Commission. The SGAM model is a very extensive multidimensional model with five different layers in multiple domains and zones [5]. COTEVOS builds further upon the work of M/490, including SGAM, the methodology and interoperability workgroups (a part of the validation of the interoperability methodology was provided by COTEVOS). The reference architecture extensively uses the layered model provided by SGAM. The zones and domains are of less use, since they focus mainly on managing the grid itself (e.g., SCADA systems), which is taken as a given within COTEVOS. Furthermore, SGAM provides a *generic* smart grid model that is applicable for Smart Grids in Europe, whereas COTEVOS requires a specific model instance for the eMobility system.

Despite their quality for their specific field of application, neither of these models fulfills the requirements that are given to a common reference architecture for interoperability testing of an electric vehicle charging infrastructure. They do not provide a common and unambiguous context for interoperability testing in the required range, as well as the current and future eMobility system in Europe is not fully captured. The current view of the future eMobility system can partly be mapped into the SGAM model, mainly by the separation of the DER Layer into multiple domains that address electric mobility needs and issues. The CEN/CENELEC model gives a view of the interfaces involved but lacks a clearer description of these interfaces as well as the ability to map services and functions onto the model.

Another disadvantage is that neither of models presents a description of responsibilities for each actor, which results in a lack of stabilization of the interfaces. The reference architecture discussed in this contribution was strongly inspired by both the CEN/CENELEC interface and the SGAM model and takes their approaches one step further into an architecture that can fulfill the requirements given by the future electric mobility environment. Furthermore, current real world implementations and developments have been taken into account.

II. COTEVOS Reference Architecture

Testing pan-European interoperability is a very sophisticated task. Roaming issues, national guidelines and different regulations for each European country are just a few of many challenges that will be encountered. The simple demand of the EV User, to be able to travel throughout Europe with its electric vehicle, raises requirements that are by far not fulfilled today. Not only the need of having a network of charging spots available, but also more basic tasks such as charging in different low voltage grids need to be fulfilled.

The eMobility system is built-up from all kinds of subsystems (i.e. system actors) and parties (i.e. human actors) that are (presumed to be) present in the market. To create an interoperable system is of utmost importance that all participants are able to talk together using the same vocabulary. For example when talking about an EMSP it should be clear what it is and what not. The basic reference architecture provides this common set of vocabulary for the COTEVOS project and all parties within the eMobility system. The requirements for the basic reference architecture are as follows:

1. Provide a common and unambiguous context for COTEVOS in the form of a basic reference architecture. All COTEVOS partners agreed to use it when specifying use cases and test cases.

2. Reflect the current and future eMobility system in Europe. The basic reference architecture should not only describe the future system but also fit the current real world situation.

3. Describe the responsibilities of each actor in the system. When the responsibilities of all the actors are clear the interfaces between the actors will be stable, creating a future proof architecture and eMobility system.

The requirements that are raised to the COTEVOS reference architecture are located in three different domains, the actor/interface domain, the service/function domain and the physical/electrical domain. The COTEVOS reference architecture is based on these domains using a 3-Layer approach. This multidimensional approach has strong similarities to the SGAM model, but clearly defines not to be an eMobility clone of the SGAM model as the three layers are focusing the testing purpose. The first layer in COTEVOS identifies the different (business/legal) actors and all the involved (visible) physical components and some required communication protocols. The second layer adds services and information being exchanged, and some additional communication requirements. The third layer makes it possible to map these services in different configurations on test labs and systems.

A. Actor/Interface Layer

Analysing the different initiatives, such as M/468 Smart Charging [4], FP7 Green eMotion project [6], eMI3, SGAM, PlanGridEV [7] and the current European electricity market [8], the actors have been identified along with their functionalities. In many cases both actors and their functionalities are similar in all initiatives (e.g., the EV, EV user and the EVSE). However, there are other actors (e.g., the EMSP) whose functionalities differ among the initiatives. Moreover, depending on the country regulatory frameworks, it could happen that some responsibility should be dealt by an actor whose functions are not defined for this actor. As a result, the COTEVOS reference architecture has been specially designed to solve these contingencies.

A.1 Actors Definition

In a very-first actors definition, based upon the activities described in the above paragraph, their interactions were omitted on purpose. These actors are aligned with Smart Grid Mandate M/490 [9] to create market models that can be feasible, realistic and profitable in the future.

- The Electric Vehicle consumes electricity when it charges, but it can also deliver energy to the grid in Vehicle to Grid (V2G) scenarios. The EV user is the actor which uses services provided by the eMobility system.
- The Electric Vehicle Supply Equipment (EVSE) is the accepted acronym for defining a charge point, charge pole, charge station, etc.; it is the physical device to charge EVs.
- The EVSE Operator (EVSEO) is the actor which manages its EVSEs and can add smart charging functions by means of the Charge Management System (CMS).
- The eMobility Service Provider (EMSP) is a key actor because it has several functions. It owns eMobility contracts with EV users, has also roaming contracts with EVSE Operators (direct or through a marketplace) that allow the EV user to charge its EV by using their EVSEs. This actor can also provide value-added services.
- The Clearing House offers clearing services between different EVSEOs and EMSPs and implements national or international roaming services. This mediation is used to avoid a high number of bilateral agreements between all EVSEOs and all EMSPs.

- There are other actors involved in the eMobility system, such as the Distribution System Operator (DSO) and the Transmission System Operator (TSO), which operates the distribution and transmission grid and facilitate a stable power system. The Original Equipment Manufacturer (OEM) offers services using proprietary protocols to its manufactured EVs and their EV Users. The Energy Market facilitates buying and selling electricity, whereas the Energy Supplier produces electricity, balances its production and provides wholesale contracts to the EMSPs and/or EVSE Operators.

Once the actors were identified, all the interactions must be defined, according to the information they produce/consume. In other words, the functionality and the interfaces they cover.

A.2 Actor-based Approach for the Reference Architecture

The actor-based architecture covers all functionalities regardless the actor which implements them. In other words, this architecture pays more attention to the actor who consumes the information than to all the involved actors within the complete chain from the data generation to the final consumption. With this concept in mind, the defined interfaces among actors are depicted in the figure 1, which gathers the interfaces in the eMobility system.

The interaction between actors (or more accurate, roles) are described by A to M interfaces (COTEVOS Interface IDs), where the final data consumer is connected to the producer. The secondary actors, OEM and energy markets are out of the scope of the COTEVOS project, as far as they use their own proprietary and energy regulated data models and interfaces.

A.3 Standard and nonstandard Interfaces

In some cases, the interfaces depicted are supported by one (or even more) communication system, standard or widely used protocol. For example, IEC 61851 [1], ISO 15118 [2] standards or other proprietary alliances such as CHAdeMO [10] can be used for the EV-EVSE interface (Fig.1 A). In other cases there are no standards, but widely adopted communication protocols and semantics are available. This is the case for OCPP [11] (Fig.1 E), which has already been adopted by many existing EVSE Operators. Nevertheless, the existence of a standard does not mean that it will be adopted by the industry. For example OCHP [12] (Fig.1 K and L) is an existing open protocol for clearing house and EMSP interoperability, but has not (yet) been adopted by any Clearing House, EVSE Operator or EMSP.

Although interaction as well as information exchange among the eMobility actors are necessary, in some cases there is not an adopted standard and likely never will be. A representative example is the way EV users access the services offered by the EMSP. Every EMSP will have its own web page or *smartphone* application available for its users. Moreover, the services that two different EMSP can offer to their customers can also be completely different.

B. Service/Function Layer

The architecture of the eMobility system is constrained by regulations, national guidelines and legacy systems that are already in place. A larger part of the eMobility system is built up from the ground (e.g., by startups), instead of a system wide top-down approach. That makes it difficult to create interoperability tests that work for each situation.

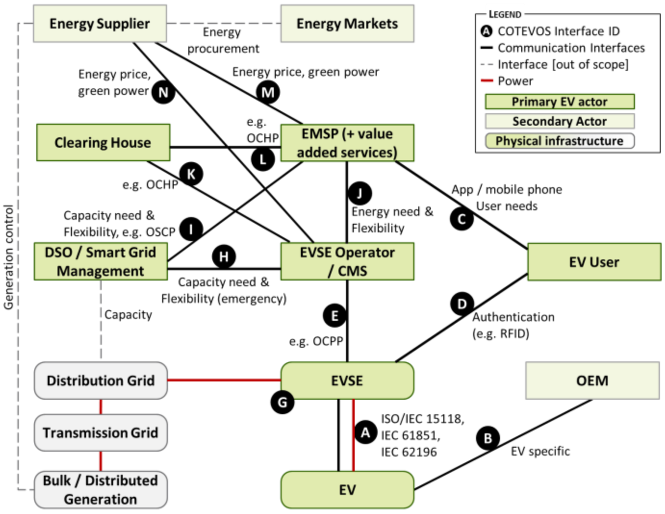

Fig. 1. COTEVOS Reference Architecture, showing the Business layer, its actors and interfaces.

Take for example a possible evolution of an EVSE Operator: It might start by selling and managing EVSEs, and gradually extend its business model to provide more sophisticated eMobility services towards customers (e.g., reservation of poles, green energy charging, smart charging). According to the COTEVOS reference architecture this EVSE Operator gradually transforms into an EVSE Operator and an EMSP, without conforming to the interfaces specified for interaction between these two actors.

Further study of the use cases currently available within the COTEVOS project [13] showed that there is no common understanding of the (business) services in the eMobility system and a mapping of these services to the actors. Without this, no stable (i.e. future proof, interoperable) interface architecture could be developed, as different stakeholders have a different view on the responsibilities of the actors. To make sure that all stakeholders have the same understanding of the eMobility system, the reference architecture needs to have more details regarding the responsibilities of each of the actors. Within COTEVOS this is done by detailing which (business) services each actor provides in a service layer.

This service layer allows for a separation of concerns within the eMobility system and shows which main services, functions and interfaces are required when dealing with the use cases in COTEVOS. The service layer resembles the functional layer of SGAM, since SGAM's function layer also describes 'functions and services including their relationships following business needs' [5]. The service definitions are based on the use cases available within COTEVOS and agreed upon by all the project partners. In figure 2 these services are visually represented by rounded boxes, and services required by other services are connected by lines. Each service provides specific functions and consequently describes the responsibilities of that service. These functions are not detailed in the figure due to

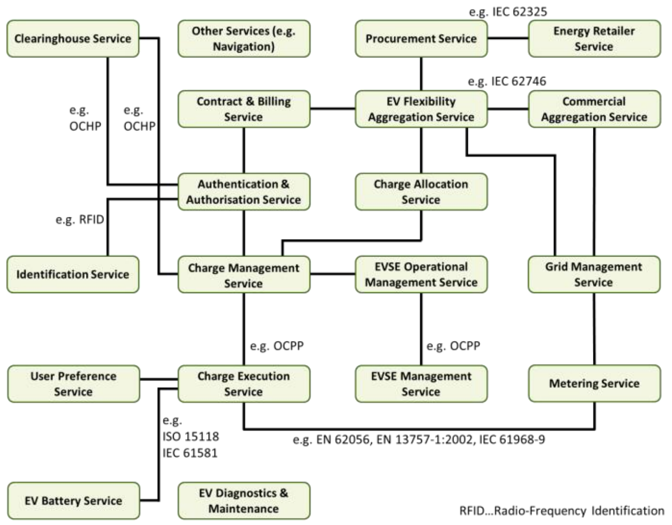

Fig. 2. COTEVOS Service layer, showing the services needed for smart charging.

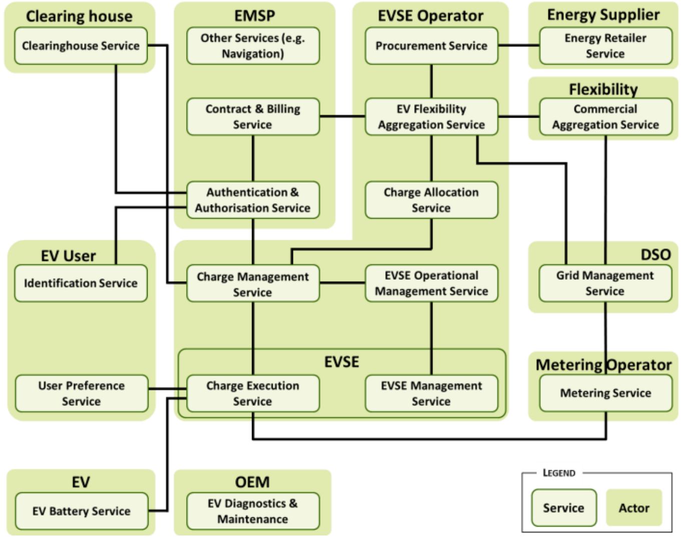

Fig. 3. COTEVOS Service layer providing a mapping example on the actor layer.

space constraints, for that refer to Deliverable 3.2 [14]. The proposed view allows the use cases to be defined in terms of services instead of actors or physical power infrastructure, making a functional specification independent from its deployment(s). This means that the interfaces between the services can be defined (and will be stable), without knowing the actual mapping of services to actors in the (eMobility) market. Furthermore, the figure helps identify gaps with respect to interfaces that need to be standardized between services and their actors.

Fig. 3 shows an example mapping of the services back to the actors. This means that for this deployment we know the responsibilities of each of the actors. This mapping may be different for another EU member state, while the services and their interfaces stay the same.

This approach is similar to the one taken to develop the EU Smart Grid Conceptual Model within the Methodology report from the M/490 mandate by CEN/CENELEC /ETSI [5]. That conceptual model is based on the Harmonized Energy Market Role Model [8] in which all actors in the EU electricity market are harmonized by using roles.

C. Laboratory/Physical Layer

The layers in the previous sections describe the actors and services within the electric mobility system and can be used as a common scheme. The additional Laboratory/Physical Layer provides an architecture approach for conformance and interoperability testing within a laboratory environment. Therefore the approach for Black-Box-Testing is used, where the test operator has no knowledge about the internal structure and functionality of the device under test (DuT). Only the interactions of the DuT with its environment have to be known and therefore the test operator can only affect the interfaces of the DuT.

The laboratory system, which is based on this architecture, must have the possibility to test every actor described in Section A. For interoperability testing the interfaces of the DuT will be influenced by mock-up components which work as counterparts for the interfaces under test. Within this layer these components are either simulated or emulated components of the actors within the reference architecture. We have chosen for the possibility to simulate several system components since the eMobility System and standards are still evolving, so often an up to date component is not available.

In order to be capable of implementing a service orientated view as given in layer 2 of the COTEVOS reference architecture several requirements need to be met. Mainly a modular design, a fast transformation of the system structure and the possibility for scaling up the testing operation meet these problems for such a laboratory reference architecture and supports the test case development described before.

Therefore it should be possible to quickly change the configuration of the test system. The focus for the device under test can be either a single actor/component or service but it is also possible to extend the DuT to a composition of several actors.

Fig. 4 shows the laboratory reference architecture developed within the COTEVOS project [14]. Every actor of the eMobility system is integrated as a simulated component. In addition one or more of these implemented components will be replaced by real-world actors like an EMSP or a clearing house. The communication between the actors is based on a Simulation Message Bus which works as a software based message router between the connected components and it allows the information transport within the whole system.

The hardware integration will also be possible using a standardized communication structure provided by the Simulation Message Bus. Thereby a real-world EV or EVSE is connected to the laboratory test system. To complete the reference architecture, a graphical user interface for visualization, logging and control must be provided. This allows a test operator to control the tests by an integrated scenario editor and compare the test results with expected ones using visualization and logging tools.

The Simulation Message Bus can be based on a TCP/IP based data exchange to provide the best flexibility with the web based actors (like the clearing house) of the eMobility system. If necessary, the flexible and modular approach of the architecture allows the simple substitution of the communication media to different ones. From an overall view the reference architecture provides a co-simulation environment with hardware integration support, which isn't only restricted to the eMobility system.

The substitution possibilities are depicted in Fig. 5. In the user interface and control software (e.g., the scenario editor) all components are abstracted implemented as proxies. Each proxy acts as a common interface for the user interface and can either represent a simulated component or a real-world based actor (e.g., a clearing house). Also an EV or EVSE as hardware based components can be controlled or represented with such proxies in the scenario editor. The information exchange between the proxies and the corresponding devices will use the Simulation Message Bus as described before. Every hardware component will have its own connector, which works as a protocol converter to the common bus system infrastructure. This configuration allows a fast replacement of simulated components by hardware based ones. It also allows a fast introduction of new communication protocols or components into the test laboratory environment.

III. DISCUSSION/VALIDATION

The described approach has been set out to create a common vocabulary regarding actors, services and labs within the COTEVOS project. The usefulness of this approach has already given us some validation of our approach.

The architectural analysis starts with the physical layer (or component layer, which is the lowest layer in SGAM), since the physical entities are a given in all use cases. Subsequently the business layer is analyzed in the context of a use case, which shows the business actors in the system and some of the interactions between them (the business layer of SGAM). From that analysis the function layer is developed. This analysis is input for a service-based view on the use case, which is independent from the actors, but can easily be mapped back to actors in the system. Based on the identified services, the information layer and subsequently the communication layer can be developed, showing the information objects, communication protocols and possible standards to implement the use case. This approach is repeatable and useful for the analysis of other systems in the Smart Grid.

The service layer proved already useful in the communication among the partners. During discussions about the reference architecture some partners identified interfaces that were not present in the architecture of other partners. By using and discussing the service layer it was identified that all partners were actually referring to the same service, though implemented by a different actor. That meant that the discussion was about the same interface between two services, but a different actor mapping in the deployment.

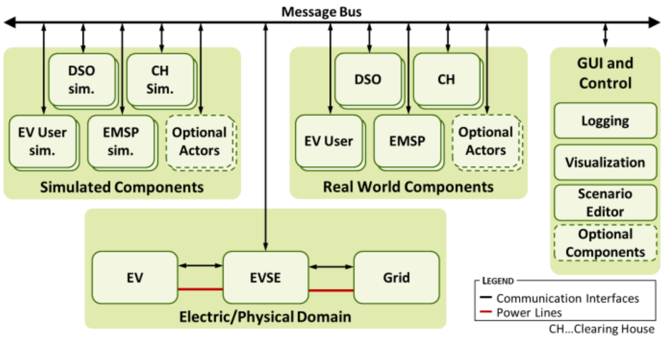

Fig. 4. COTEVOS Laboratory/Physical layer, showing a framework for an EV/EVSE test system implementation [14]

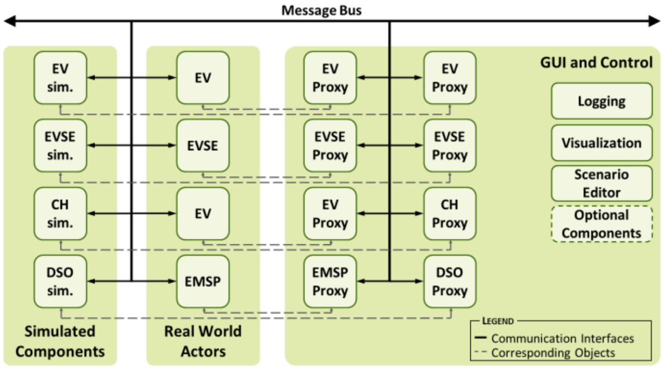

Fig. 5. Test scenario execution with simulated/real-word components [14]

Another discussion point is the usage of standards and open protocols. In some cases, several standards are available for the same interface. The most relevant one is the EV-EVSE interface, where several standards and even alliances are available with different functionalities. As a result, the actor decides whether to implement one or more standards for the same functionality.

In addition, the existence of a standard for an interface does not mean that the eMobility actors are willing to adopt it. This fact depends on several factors, such as the complexity of the standard, the lack of functionalities it has or if it complies with the different countries' regulatory frameworks.

For the COTEVOS Reference Architecture it is not relevant how the actors' interfaces are implemented, but the information exchange which actually manages those interfaces. This allows also laboratories to choose to implement any standard map into the proper interface. Furthermore, the reference architecture helped identify gaps with respect to missing interfaces among actors and/or services. In analyzing the interfaces between the actors, interface J (interface between the EVSE Operator and EMSP) is identified as a gap, as no known standards are available there to test interoperability (i.e. current real-world implementations – if available – use a proprietary protocol). This also holds for interfaces N and M (interfaces towards the Energy Supplier) which could be covered by OpenADR in a future iteration and interfaces H and I (towards the DSO) where the Open Smart Charging Protocol (OSCP) could be a candidate.

The COTEVOS reference architecture describes all the actors and their interfaces in the eMobility system. This architecture therefore provides a common and unambiguous context for all use cases and test cases developed in the COTEVOS project, reflects the current and future eMobility system in Europe, it is adaptable to the different countries regulatory frameworks and describes what information is exchanged among the actors.

The reference architecture is well aligned, and shares many similarities with the work produced in the Green eMotion FP7 project, eMI3, and the CEN/CENELEC/ETSI group on Smart Charging and the Smart Grid Coordination Group's activities mandated in M/490 by the European Commission, but in COTEVOS we have strived to make a common denominator. The modular approach enables the integration of new additions in the future.

Compared to the current state of the art there is no gap in the COTEVOS Reference Architecture itself. Furthermore, it shows that COTEVOS is able to test the eMobility standards related to real EVs, EVSEs and EVSE Operators in the different laboratories, and as such perform round robin tests for EV's and EVSE's which will be completed during the rest of the project. The generic approach that was utilized during the generation of the reference architecture allows future additions such that the architecture will be able to stay aligned with future needs. The Simulation Message Bus allows laboratory collaboration, which grants that a laboratory can test use cases which are offered by other COTEVOS laboratories when testing DuT.

The remainder of the validation of this reference architecture will be conducted within the seven different European laboratories (AIT, TNO, DTU, TUL, Tecnalia, IWES and RSE) that are currently set up for interoperability testing within the eMobility system. During the interoperability, conformance and round-robin tests this approach will have to prove itself further. Results will be documented in the upcoming deliverable 3.3 and 4.3 provided by the COTEVOS consortium.

IV. CONCLUSION

The COTEVOS reference architecture describes all the actors, their interfaces and the exchanged information in the eMobility system. It also provides a context for defining use cases and test cases that reflect the current and future eMobility systems. This reference architecture is strongly aligned with the different existing initiatives, such as Green eMotion FP7 project, eMI3, the CEN/CENELEC/ETSI group on Smart Charging and the Smart Grid Coordination Group's activities.

This architecture is designed for interoperability at three layers. The first one is the actor/interface layer, describing the interactions between different actors and the interface used therefore. The second layer is the service/function layer, which describes the system as business related services which might be located at different actors or interfaces in different use-cases. The third layer is the physical/laboratory layer designed for the real implementation within testing facilities, taking reusability and interoperability between different laboratories into account.

With this three layer approach the COTEVOS reference architecture enables a holistic analysis of compliance and interoperability within the eMobility environment. In addition, it provides the required framework to include the necessary links to the smart grid.

Within the COTEVOS project the developed architecture will be used for interoperability, conformance and round robin tests and thereby it will be further evaluated and if required improved.

ACKNOWLEDGMENT

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REFFERENCES

[1] Standard IEC 61851-1 – Electric Vehicle Conductive Charging System - Part 1: General Requirements, Std. 61 851-1, 2010.

[2] Standard ISO 15118-1 – Road Vehicles - Vehicle to grid communication Interface - Part 1: General Information and Use-case Definition, Std. 15 118-1, 2013.

[3] (2015) COTEVOS – Developing Capacities for Electric Vehicle Interoperability Assessment. [Online]. Available: http://cotevos.eu/

[4] (2011) Standardization for road vehicles and associated infrastructure. CEN/CENELEC. [Online]. Available: ftp://ftp.cen.eu/CEN/Sectors/List/Transport/Automobile/EV_Report_incl_annexes.pdf

[5] (2014) CEN/CENELEC/ETSI Smart Grid Coordination Group (M/490): Working group Interoperability. Methodologies to facilitate Smart Grid system interoperability through standardization, system design and testing. [Online]. Available: ftp://ftp.cencenelec.eu/EN/EuropeanStandardization/HotTopics/SmartGrids/SGCG_Methodology_Overview.pdf

[6] The Green eMotion project – preparing the future of European electromobility. [Online]. Available: http://www.greenemotion-project.eu/

[7] (2015) PlanGridEV – Distribution grid planning and operational principles for EV mass roll-out while enabling DER integration. [Online]. Available: http://www.plangridev.eu/

[8] (2014) ENTSO-E, The Harmonized Electricity Market Role Model, Version 2014-01, [Online]. Available: https://www.entsoe.eu/fileadmin/user_upload/edi/library/role/harmonised-role-model-2014-01_approved.pdf

[9] EC Directorate General for Energy, Smart Grid Mandate – Standardization Mandate to European Standardization Organisations (ESOs) to support European Smart Grid Deployment, M/490 EN, Brussels, 1st March 2011.

[10] (2015) CHAdeMO Association. [Online]. Available: http://www.chademo.com/

[11] (2015) Open Charge Alliance – Open Charge Point Protocol. [Online]. Available: http://www.ocpp.nl/

[12] (2015) Open Clearing House Protocol. [Online]. Available: http://www.ochp.eu/

[13] COTEVOS Deliverable 1.1: Report on the needs for interoperability between EVs and electrical power system. Date 30/06/2014, version 1.0. [Online]. Available: http://cotevos.eu/wp-content/uploads/2014/08/D1.1-Report-on-the-needs-for-interoperability-between-EVs-and-electrical-power-system.pdf

[14] COTEVOS Deliverable 3.2: Set-up of the reference architectures in some of COTEVOS' infrastructures. Date 14/11/2014, version 15.